JUN 16 1972

ED2/72/362

MEMORANDUM

TO: ES2/Chief, Structures Branch

FROM: ED2/Manager, Lunar Experiments Project Office

SUBJECT: Apollo Lunar Surface Drill Bore Stem Design

Martin Marietta Corporation has submitted the Bore Stem Structural Analysis Report (enclosure 1) for NASA's review and approval. Since redesigning the bore stem joint was your recommendation, we are requesting your office support us in the review and approval of this design. We would also like your concurrence prior to approval of this analysis report. A Preliminary Design Review is scheduled for 1:30 PM on June 19, 1972, in room 275 of Building 16.

The Bore Stem Test Report (enclosure 2) is submitted for your information, since your office supported these tests at Martin Marietta.

For any information concerning the above review, please contact J. Sanders, X3811.

Signed by:
John A. Langford jn

P. Donald Gerke

2 Enclosures

cc: (w/o enclosures)
PA/G. S. Lunney
PG/ J. F. Goree

ED2:jmd JMSanders:ec:6-16-72:3811

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CONCURRENCES

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APOLLO LUNAR SURFACE DRILL

BORE STEM STRUCTURAL ANALYSIS REPORT

June, 1972

by

John R. Lager

MARTIN MARIETTA CORPORATION
Denver Division
P. O. Box 179
Denver, Colorado 80201

TABLE OF CONTENT

I. INTRODUCTION

The end fittings of the Apollo Lunar Surface Drill have been modified to provide additional margins of safety against possible structural failure. This report summarizes preliminary structural analysis which verifies the added strength of the modified drill stems. Failure modes which provide the least margin of safety or where simplifying assumptions used are questionable may require more detailed analysis using better analysis methods and less restrictive assumptions.

II. MATERIALS

The bore stems utilize four different materials; titanium, boron/epoxy, glass/epoxy and M674A adhesive. The end fittings are machined from 6A1-4V alloy bar. The bore stems contain E801/792 S/HTS glass roving and Narmco 5505 boron/epoxy tape. The end fittings and bore stems are joined using M674A adhesive. Mechanical and physical properties of these four materials are summarized in Table 1.

III. END FITTING DESIGN

The titanium end fittings 467A8060014-003 and -005 have been modified as shown in Figure 1. The new multiple step design allows for more efficient transfer of load from the titanium fittings to the individual fibrous composite laminae. The dimensions of the individual composite laminae in the bore stem wall are shown in Figure 2. The strength of the new fitting and bond strength required to fully develop the capability of the fibrous composite laminae can now be calculated.

A. AXIAL TENSILE LOADING

Calculate load assuming the three boron/epoxy layers resist all of the applied tensile loading and that a stress of 190,000 psi fully develops the capability of the boron/epoxy.

Load -

$$P = \sigma A = 190,000(3.14)(0.930)(0.016)$$

$$P = 8,870 \text{ lb}$$

Bond Shear - If bond shear strength is critical, the allowable axial load is

$$P_a = \tau_a A = 2,100(1.48)(3.14)(0.930)$$

$$P_a = 9,080 \text{ lb}$$

Titanium Fitting - If stress in the titanium fitting is critical, the allowable axial load is

$$P = \sigma_a A = 140,000(3.14)(0.899)(0.067)$$

$$P = 26,500 \text{ lb}$$

B. TORSIONAL LOADING

Calculate load assuming that the two inner and one outer $\pm 45^{\circ}$ layer of glass/epoxy resists all of the applied torsional loading and that a stress of 35,000 psi fully develops the capability of the glass/epoxy.

Torque -

$$T = \tau A r = 35,000(3.14)(0.930)(0.036)(0.460)$$

$$T = 1690 \text{ in-lb} = 140 \text{ ft-lb}$$

Bond Shear - If bond shear in torsion is critical, the allowable torque is

$$T = \tau_a A r = 2,100(3.14)(0.930)(1.48)(0.46)$$

$$= 4,180 \text{ in.-lb or } 348 \text{ ft-lb}$$

IV. FIBROUS COMPOSITE BORE STEMS

The fibrous composite bore stems 467A8060015-009, -019 and -029 assemblies have been modified in the end regions to interface with the new multiple step end fittings. A comparison of the old and new designs is shown in Figure 3. The structural capability of the bore stems in bending, torsion and axial compression can now be investigated.

A. BENDING

The allowable applied bending moment will be calculated assuming that the critical failure mode is tensile strength of the boron/epoxy laminae. The critical section will be considered to be at the end of the titanium fitting where three layers of boron/epoxy and one inner and one outer layer of $\pm 45^\circ$ glass/epoxy are effective. The mechanical properties of glass/epoxy oriented at $\pm 45^\circ$ are calculated in the Appendix.

1. Moment Allowable $M_a = \dfrac{\sigma_{all.} I}{C}$

$$I = \pi t_{eq} r^3$$

where t_{eq} is equivalent wall thickness.

$$t_{eq} = 0.016 + 0.024 \left(\frac{E_{GL/E}}{E_{B/E}}\right) =$$

$$0.016 + 0.024 \left(\frac{2.2}{28.6}\right) = 0.016 + 0.00185 = 0.01785$$

$$I = 3.14(0.01785)(0.462)^3 = 5.52 \times 10^{-3} \text{ in.}^4$$

$$M_a = \frac{190{,}000(5.52 \times 10^{-3})}{0.470} \doteq 2{,}230 \text{ in.-lb}$$

$$M_a = 2{,}230 \text{ in.-lb, or } 186 \text{ ft-lb}$$

2. Deflection

The bending deflection at the ends of the 28-inch and 54-inch bore stems, assuming that one end is perfectly fixed and a concentrated load P is applied at the free end, can be computed using

$$\Delta = \frac{PL^3}{3EI}$$

The loads P which result in a maximum bending stress for each of the stems is

$$P \text{ (28-inch stem)} = \frac{M_a}{L} = \frac{2{,}230}{28} = 79.5 \text{ lb}$$

$$P \text{ (54-inch stem)} = \frac{M_a}{L} = \frac{2{,}230}{54} = 41.3 \text{ lb}$$

therefore

$$\Delta \text{ (28-inch stem)} = \frac{PL^3}{3EI} = \frac{79.5(28)^3}{3(28{,}600{,}000)(5.52 \times 10^{-3})}$$

$$= 3.68 \text{ inches}$$

$$\Delta \text{ (54-inch stem)} = \frac{PL^3}{3EI} = \frac{41.3(54)^3}{3(28{,}600{,}000)(5.52 \times 10^{-3})}$$

$$= 13.78 \text{ inches}$$

3. Local Buckling

A preliminary check on local instability of the bore stem wall in bending will be obtained under C of this section by checking the stability of the wall under a uniformly distributed axial compressive stress equal to the maximum compressive stress obtained in bending.

B. TORSION

The allowable applied torque will be calculated assuming that the critical failure mode is shear strength of the $\pm$ 45° glass/epoxy laminae. The equivalent wall for strength calculations will be considered to consist of one inner and one outer $\pm$ 45° glass/epoxy layer, the 20° glass flutes, and three 0° boron/epoxy layers. Stiffness calculations will also include the other $\pm$ 45° inner layer of glass/epoxy.

1. Torque Allowable $\qquad T = \dfrac{\tau J}{r}$

$$J = 2t_{eq} \pi r^3$$

where t_{eq} is equivalent wall thickness.

$$t_{eq} = 0.024 + 0.016\left(\frac{G_{1_{2\ B/E}}}{G_{1_{2\ GL/E}}}\right) + 0.0149\left(\frac{G_{1_{2\ 20^\circ}}}{G_{1_{2\ 45^\circ}}}\right)$$

$$= 0.024 + 0.016\left(\frac{0.75}{1.035}\right) + 0.0149\left(\frac{0.785}{1.035}\right)$$

$$= 0.024 + 0.0115 + 0.0113$$

$$= 0.0468 \text{ inches}$$

$$J = 2(0.0468)(3.14)(0.460)^3$$

$$= 28.6 \times 10^{-3} \text{ in.}^4$$

$$T_{allow.} = \frac{\tau J}{r} = \frac{27{,}000(28.6 \times 10^{-3})}{0.46}$$

$$= 1{,}680 \text{ in.-lb or } 140 \text{ ft-lb}$$

2. Rotation

$$\theta = \frac{TL}{JG}$$

$$J = 2t_{eq}\ \pi\ r^3$$

$$t_{eq} = 0.0468 + 0.012 = 0.0588 \text{ in.}$$

$$J = 2(0.0588)(3.14)(0.460)^3$$

$$= 35.8 \times 10^{-3} \text{ in.}^4$$

for L = 48.35 in. (long stem)

$$\theta = \frac{TL}{JG} = \frac{1680(48.35)}{35.8 \times 10^{-3}(1,035,000)} = 2.13 \text{ radians}$$

$$= 2.13 \text{ radians or } 126^{\circ} \text{ or } 0.9 \text{ degrees per ft-lb torque}$$

for L = 25.5 in. (short stem)

$$\theta = \frac{TL}{JG} = \frac{1680(25.5)}{35.8 \times 10^{-3}(1,035,000)} = 1.16 \text{ radians}$$

$$= 1.16 \text{ radians or } 66^{\circ} \text{ or } 0.47 \text{ degrees per ft-lb torque}$$

3. Local Buckling

A preliminary evaluation of the torsion stability of the bore stem will be made using an equivalent thickness and an average modulus obtained from $E = \sqrt{E_1 \ E_2}$. The order of magnitude of the allowable torque obtained can be used to determine the desirability of proceeding with more sophisticated analysis.

$$\text{allowable torque } T = \frac{\tau_{cr} \ J}{r}$$

where

$$\tau_{cr} = \frac{E_{eq}}{3\sqrt{2}\ (1 - \mu^2)^{3/4}} \left(\frac{t_{eq}}{R}\right)^{3/2}$$

$$E_{eq} = \sqrt{E_1 \ E_2} = \sqrt{9.83 \times 10^6 (1.92 \times 10^6)}$$

$$= \sqrt{18.9 \times 10^{12}} = 4.36 \times 10^6$$

$$t_{eq} = 0.052 \text{ in.}$$

$$(\mu^2)_{eq} = \mu_{1_2} \ \mu_{2_1} = 0.0125$$

$$\tau_{cr} = \frac{4.36 \times 10^6}{3(1.414)(.9875)^{0.75}} \left(\frac{0.052}{0.46}\right)^{1.5}$$

$$\tau_{cr} = 1,020,000(0.113)^{1.5} = 1,020,000(0.0379) = 38,700 \text{ psi}$$

and therefore

$$T_{allow.} = \frac{\tau_{cr} J}{r} = \frac{38,700(2)(.052)(3.14)(.46)^3}{0.46}$$

$$T_{allow.} = 2,680 \text{ in.-lb, or } 223 \text{ ft-lb}$$

C. AXIAL COMPRESSION

Maximum applied axial compression load will be assumed to be that which results in a stress level in the boron/epoxy material of 190,000 psi. This was computed in Section III to be 8,870 pounds. The critical loads for local instability and overall Euler column buckling can now be computed and compared to the critical load for maximum stress.

1. Local Instability

The critical stress can be computed from

$$\sigma_{cr} = \sqrt{E_L E_T}\left(\frac{t}{R}\right)\sqrt{\frac{1}{3(1 - \mu_{L_T}\mu_{T_L})}}\sqrt{\frac{1 + \sqrt{\frac{E_L}{E_T}}\left[\mu_{T_L} + 2(1 - \mu_{L_T}\mu_{T_L})\frac{G_{L_T}}{E_L}\right]}{1 + \frac{1}{2}\sqrt{\frac{E_T}{E_L}}\left(\frac{E_L}{G_{L_T}} - 2\mu_{L_T}\right)}}$$

The following values will be assumed for the bore stem:

$t = 0.052''$

$E_L = 9,830,000$

$E_T = 1,920,000$

$G_{L_T} = 958,000$

$\mu_{L_T} = 0.25$

$\mu_{T_L} = 0.05$

$R = 0.46$

then,

$$\sigma_{cr} = \sqrt{18.9 \times 10^{12}}\,(0.113)\sqrt{\frac{1}{2.96}}\sqrt{\frac{1 + \sqrt{5.12}\,[0.05 + 1.975(.0975)]}{1 + \frac{1}{2}\sqrt{.195}\,(10.25 - 0.5)}}$$

$$= 4.36 \times 10^{6}\,(0.113)(0.582)\sqrt{\frac{1 + 2.27(0.2425)}{1 + 0.221(9.75)}}$$

$$= 0.26 \times 10^{6}\sqrt{\frac{1.55}{3.16}} = 0.26 \times 10^{6}\,(0.70) = \underline{182,000 \text{ psi}}$$

which would require an applied axial compressive load of

$$P = \sigma A = 182,000(3.14)(0.92)(0.052)$$

$$P = 27,200 \text{ lb}$$

The applied bending moment which would result in a maximum compressive stress of 182,000 psi can be computed from

$$M_{allow.} = \frac{\sigma I}{c} = \frac{182,000(3.14)(0.052)(0.46)^3}{0.46}$$

$$M_{allow.} = 182,000(0.1635)(0.212) = 6,300 \text{ in.-lb, or } 524 \text{ ft-lb}$$

2. Overall Column Buckling

The critical overall Euler buckling load can be computed from

$$P_{cr} = \frac{\pi^2 E_{eq} I}{L^2} = \frac{(3.14)^2(9,830,000)(3.14)(0.052)(0.46)^3}{(54)^2}$$

$$P_{cr} = 532 \text{ lb}$$

V. ANALYSIS RESULTS SUMMARY

A summary of the results of the structural analysis study are given below. A second column is given which represents the respective values at 200°F assuming that modulus values of the boron/epoxy and glass/epoxy are reduced by 5 percent and strength values by 15 percent. One particular strength value, shear strength of ± 45° glass/epoxy, will be assumed to be reduced by 67% at 200°F. This is an assumed value based on high temperature interlaminar shear strength reduction. The strength and modulus of the titanium are assumed to remain unchanged at 200°F and the lap shear strength of the M674A adhesive is assumed to increase by 20 percent at 200°F.

	Allowable Loading	
	R.T.	200°F
END FITTINGS		
a. maximum axial load (composite stress)	8,870 lb	7,530 lb
b. axial bond shear stress	9,080 lb	10,900 lb
c. maximum torque (composite stress)	140 ft-lb	46.2 ft-lb
d. torsional bond shear stress	348 ft-lb	418 ft-lb
e. maximum titanium stress	26,500 lb	26,500 lb
COMPOSITE BORE STEM		
a. allowable bending moment (max. stress)	186 ft-lb	158 ft-lb
b. cantilever deflection (28 in. stem)	3.68 in.	3.50 in.
c. cantilever deflection (54 in. stem)	13.78 in.	13.10 in.
d. allowable torque (maximum stress)	140 ft-lb	46.2 ft-lb
e. rotation (28 in. stem)	66°	62.5°
f. rotation (54 in. stem)	126°	120°
g. allowable torque (local buckling)	223 ft-lb	212 ft-lb
h. maximum axial load (local buckling)	27,200 lb	25,800 lb
i. equivalent moment allowable (local buckling)	524 ft-lb	445 ft-lb
j. maximum axial load (overall buckling)	532 lb	505 lb

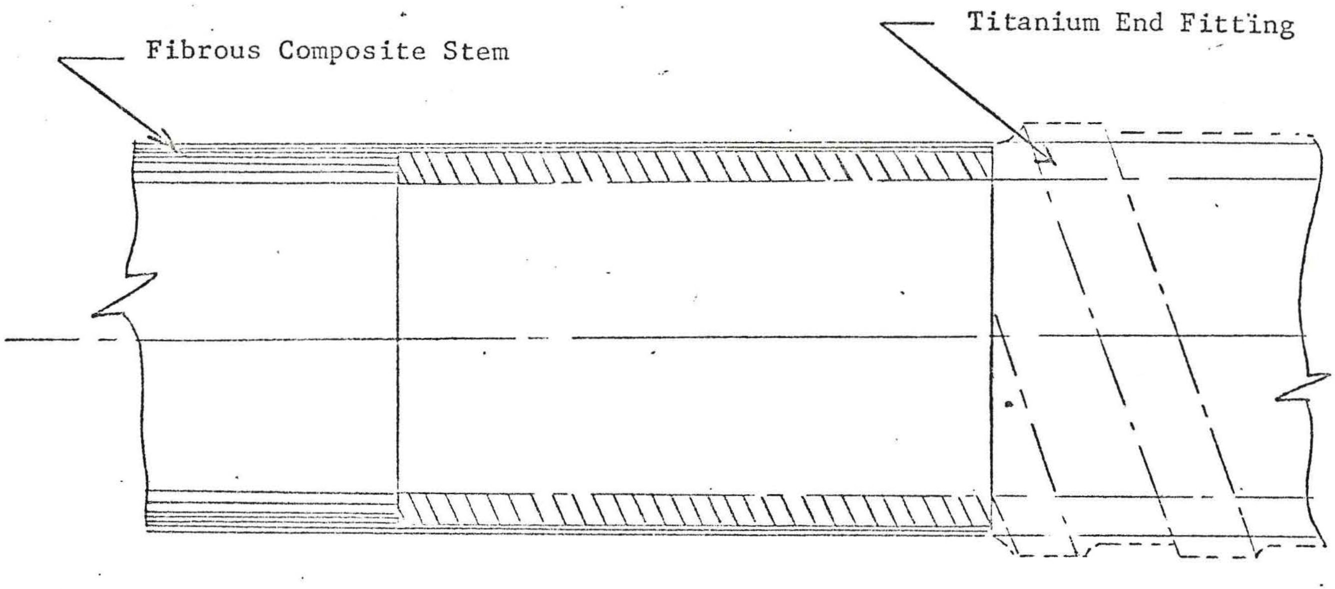
The critical loading conditions at 200°F are shown to be 505 pounds axial compression, 158 ft-lb bending and 46.2 ft-lb torque. Respective values at room temperature are 532 pounds, 186 ft-lb, and 140 ft-lb.

VI. CONCLUSIONS

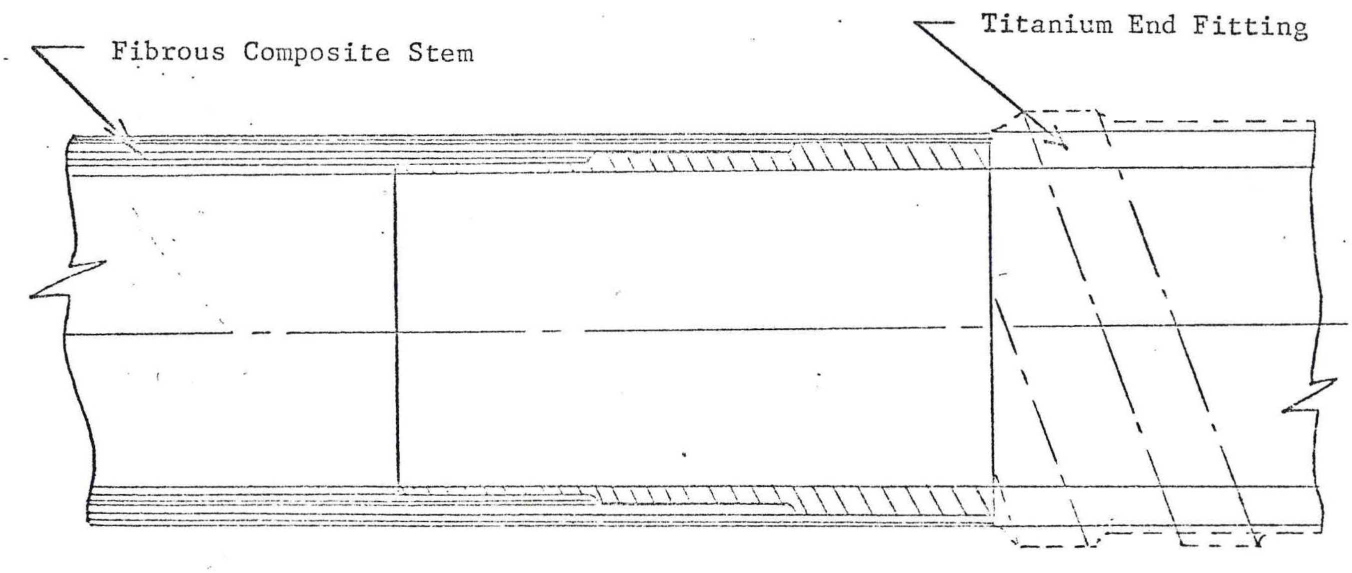
Preliminary analysis reveals no areas of concern for strength or stability of the lunar surface drill with the modified end fittings. Structural development testing will be done to verify the analysis results.

Table 1 - Material Properties

PROPERTY	BORON/EPOXY	E-GLASS/EPOXY	TITANIUM	M674A ADHESIVE
Density, ρ lb/in.^{3}	0.072	0.075	0.160	0.045
Fiber Percentage, V_f %	47.6	65	-	-
Long. Young's Modulus, E_1 psi	28,600,000	6,000,000	16,000,000	300,000
Trans. Young's Modulus, E_2 psi	2,860,000	1,450,000	16,000,000	300,000
Shear Modulus, G_{12} psi	750,000	440,000	6,400,000	120,000
Long. Poisson's Ratio, μ_{12}	0.30	0.33	0.33	0.33
Trans. Poisson's Ratio μ_{21}	0.01	0.05	0.33	0.33
Compressive Strength, σ_c psi	300,000	70,000	146,000	20,000
Tensile Strength, σ_t psi	190,000	175,000	140,000	15,000
Interlaminar Shear Str., $\tau_{i.s.}$ psi	10,000	8,800	70,000	7,500
Bond Strength, τ_b psi	-	-	-	2,100



OLD DESIGN



NEW DESIGN

Figure 1 - End Fitting Design Modification

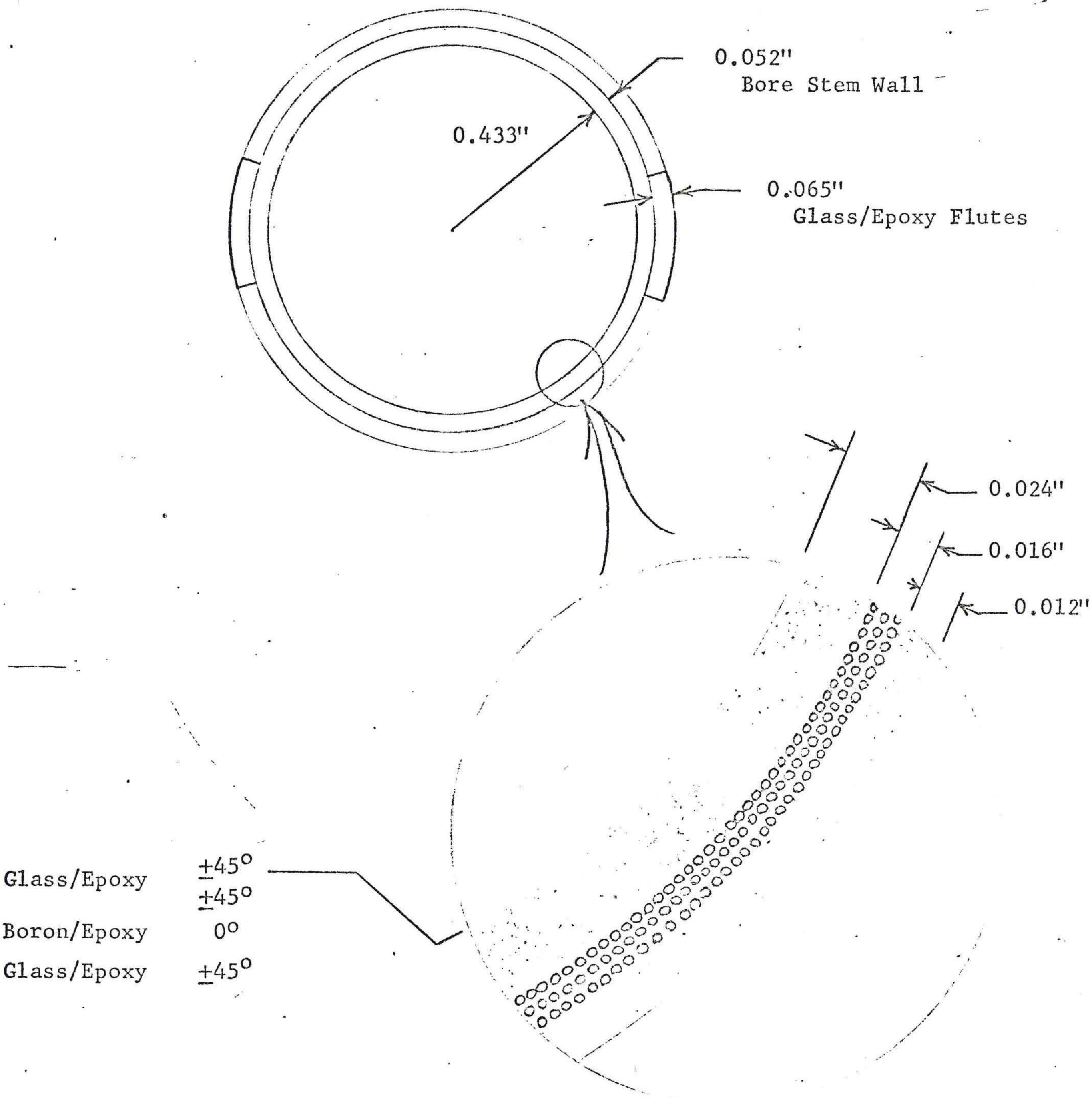


Figure 2

Lunar Surface Drill Stem
Composite Wall Geometry

APPENDIX

Off-Axis Laminate Properties

The material constants of an orthotropic laminate with major and minor axis 1,2 rotated on angle θ with respect to the axis x,y can be calculated from:

$$E_x = E_1 \Big/ \left(\cos^4\phi + \frac{E_2}{E_1}\sin^4\phi + \frac{1}{4}\sin^2 2\phi \left(\frac{E_1}{G_{1_2}} - 2\,\mu_{1_2} \right) \right)$$

$$E_y = E_2 \Big/ \left(\cos^4\phi + \frac{E_2}{E_1}\sin^4\phi + \frac{1}{4}\sin^2 2\phi \left(\frac{E_2}{G_{1_2}} - 2\,\mu_{2_1} \right) \right)$$

$$G_{x_y} = E_1 \Big/ \left[\left(\frac{E_1}{E_2} + 2\,\mu_{1_2} + 1 \right) - \left(1 + 2\,\mu_{1_2} + \frac{E_1}{E_2} - \frac{E_1}{G_{1_2}} \right) \left(\cos^2 2\phi \right) \right]$$

$$\mu_{x_y} = \frac{E_x}{E_1} \left(\mu_{1_2} - \frac{1}{4}\sin^2 2\phi \right) \left(\frac{E_1}{E_2} - \frac{E_1}{G_{1_2}} + 2(\mu_{1_2} + 1) \right)$$

$$\mu_{y_x} = \frac{E_y}{E_2} \left(\mu_{2_1} - \frac{1}{4}\sin^2 2\phi \right) \left(\frac{E_2}{E_1} - \frac{E_2}{G_{1_2}} + 2(\mu_{2_1} + 1) \right)$$

$$\mu_{2_1} = \frac{E_2}{E_1}\,\mu_{1_2}$$

$$\phi = \theta_{deg}\,\frac{\pi}{180}$$

Calculation of the torsional stiffness of the bore stem requires that the shear modulus G_{x_y} be calculated for $\pm 45^\circ$ and 20° glass/epoxy. The material constants used are:

$$E_1 = 6{,}000{,}000 \text{ psi}$$
$$E_2 = 1{,}450{,}000 \text{ psi}$$
$$G_{1_2} = 580{,}000 \text{ psi}$$
$$\mu_{1_2} = 0.33$$
$$\mu_{2_1} = 0.05$$

then for $\theta = 45^o$

$$G_{x_y} (\pm 45^o) = \frac{6{,}000{,}000}{\left[(4.14 + 0.66 + 1) - (1 + 0.66 + 4.14 - 10.35) \cos^2 90^o \right]}$$

$$G_{x_y} (\pm 45^o) = \frac{6{,}000{,}000}{5.80} = 1{,}035{,}000 \text{ psi}$$

and for $\theta = 20^o$

$$G_{x_y} (20^o) = \frac{6{,}000{,}000}{\left[(4.14 + 0.66 + 1) - (1 + 0.66 + 4.14 - 10.35) \cos^2 90^o \right]}$$

$$G_{x_y} (20^o) = \frac{6{,}000{,}000}{\left[5.80 - (-4.67)(0.413) \right]} = 775{,}000 \text{ psi}$$

Calculation of the bending stiffness of the bore stem requires that the Young's modulus E_x be calculated for $\pm 45^o$ glass/epoxy.

For $\theta = 45^o$

$$E_x (45^o) = \frac{6{,}000{,}000}{\left[\cos^4 \frac{\pi}{4} + 0.242 \sin^4 \frac{\pi}{4} + \frac{1}{4} \sin^2 \frac{\pi}{2} (10.35 - 0.66) \right]}$$

$$E_x (45^o) = \frac{6{,}000{,}000}{\left[0.25 + 0.0605 + 0.25(9.69) \right]} =$$

$$E_x (45^o) = \frac{6{,}000{,}000}{2.73} = 2{,}200{,}000 \text{ psi}$$

6-8-72

4

APOLLO LUNAR SURFACE DRILL
BORE STEM TEST REPORT

Document No. 467A8060906

May 23, 1972

MARTIN MARIETTA CORPORATION
DENVER DIVISION
DENVER, COLORADO 80201

1.0 Introduction

After delivery of ALSD Flight Unit bore stems, NASA-MSC/SMD questioned the effects of localized delaminations of the boron/fiberglass structure. The ALSD Program, having tested this condition (inclusive of Qualification Tests), could establish no technical bases for rejecting such bore stems. Between delivery and the Apollo 16 flight, two (2) 54-inch bore stems were downgraded by NASA-MSC from flight to test articles. MMC-Denver and NASA Lunar Surface Project Office (LSPO) proposed a test sequence to demonstrate the design margins in the bore stems, using these two stems as test articles. This report presents the results of these tests, including a copy of the "as-run" test procedure. These tests were witnessed by representatives from NASA-MSC [LSPO, ASPO, Quality, SMD, S&AD, and RMO-R&QA] , HFE Principal Scientist, and Air Force Quality Assurance.

2.0 Test Description

The test activities were organized to verify the structural integrity of the bore stem, perform extensive drilling tests to exceed 40-minutes of power-on time (Apollo 15 and 16 required 2½-5 minutes of power-on time per hole) , determine if the bore stem joint could still transmit maximum torque, then determine the lateral loading required to fail the bore stem.

2.1 <u>Torque Tests</u> - Torque tests were performed by static loading of the bore stem in a test fixture (See Figure 1). Loading was applied to 22-foot pounds (maximum drill power head capability).

2.2 Drilling Tests - The bore stems were exposed to a normal drilling mission in the dense lunar simulation model at MMC-Denver (See Figure 2). To allow testing to the full 8-feet depth, residual 28-inch bore stems were added to the test specimen, as would normally be done in a drilling mission. At the conclusion of each drilling mission (approximately 10-minutes of power-on time), the critical areas and the known areas of delamination were examined for visual evidence of degradation.

2.3 Lateral Load Tests - With the 54-inch bore stem rigidly emplaced in the lunar simulation model and with the drill power head attached, a force was applied with a spring-scale to the power head which exposed the bore stem to bending. The force was gradually increased until the bore stem failed.

3.0 Test Results

The bore stem tests demonstrated the capability to sustain four (4) drilling missions, where each mission was an extreme case of 10-minutes of drill power-on time. The two Apollo lunar drilling missions required 2½-5 minutes per hole. Testing also verified that the joint area was susceptible to bending failure. Design alternatives for this condition are available and discussed in paragraph 4.0. The "as-run" procedure is attached as Appendix A to this report.

3.1 Pre-drilling Torque Tests - The F-20 bore stem was torqued to 22-foot-pounds to verify the torsional integrity of the stem and in particular the delaminated area at the joint. The applied torque resulted in a 23° torsional deflection with no visible degradation to the stem.

The second 54-inch stem had previously been tested to 22-foot pounds, and there was not requirement to repeat this test <u>prior to</u> drilling.

3.2 <u>Drilling Tests</u> - Each bore stem was subjected to the equivalent of four (4) drilling missions or 40-minutes of total drilling time. In both stems the erosion of the helical flutes (cutting transport system) was the reason for stopping the drilling tests, as shown in Figure 3. There was no visible degradation to the bore stem structure after the drilling tests. The delaminated areas showed no change during or after the drilling tests.

3.3 <u>Post-drilling Torque Tests</u> - Following the drilling tests, the F-20 bore stem was torqued to 22-foot-pounds without failure. The second item was torqued to 22-foot-pounds, at which time it was decided to increase the loading until failure. Torque loads to 85-90 foot-pounds caused some audible results, but there were no visible indications of crazing or failure. With this demonstration of design margin, it was decided to proceed with lateral loading.

3.4 <u>Lateral Loads Tests</u> - The F-20 bore stem was re-drilled into the lunar simulation model. Since the flute wear was significant, a stall torque (22-foot-pounds) was developed while drilling. In this combined load condition, a lateral load was applied 15-inches above the bore stem threaded fitting. The joint failed with an applied load of 31-pounds or a bending moment of 39-foot-pounds.

The second 54-inch stem was also redrilled into the lunar simulation model. With no power on the drill, a lateral load of 42-pounds was applied. The bore stem failed in the middle of the stem at a bending moment of 168-foot-pounds. At this time, the threaded joint area was crazing under a 68-foot-pound bending moment.

The bore stems, after lateral load failures, are shown in Figures 4 and 5. It should be noted that the complete joint failure has no sharp edges and no blockage to prevent passage of the heat flow probe. Additionally, the extent of the flute wear is apparent when comparing the flute depths of Figure 3 (heavily worn) with the depths of Figure 5 (minimal wear).

4.0 Conclusions

These tests have demonstrated the significant drilling margins in the bore stems, as well as the fact that the delaminated conditions did not reduce the drilling performance.

The lateral loading sensitivity was demonstrated by the failure at 39-foot-pounds. This data combined with the deliberate breaking of six additional stems showed a scatter as follows:

39 foot-pounds	2 joints
48½ foot-pounds	1 joint
52 foot-pounds	1 joint
56 foot-pounds	1 joint
59½ foot-pounds	2 joints
68 foot-pounds	1 joint

A design improvement has been developed to significantly increase the lateral load capability of the bore stem joint. This design involves the extending of additional boron laminations over the titanium fitting. Authorization to implement this change has been received.

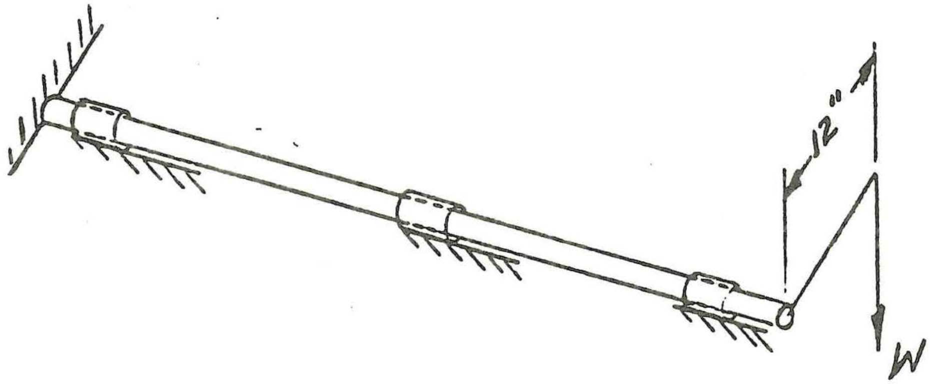


Figure 1 Bore Stem Torque Test

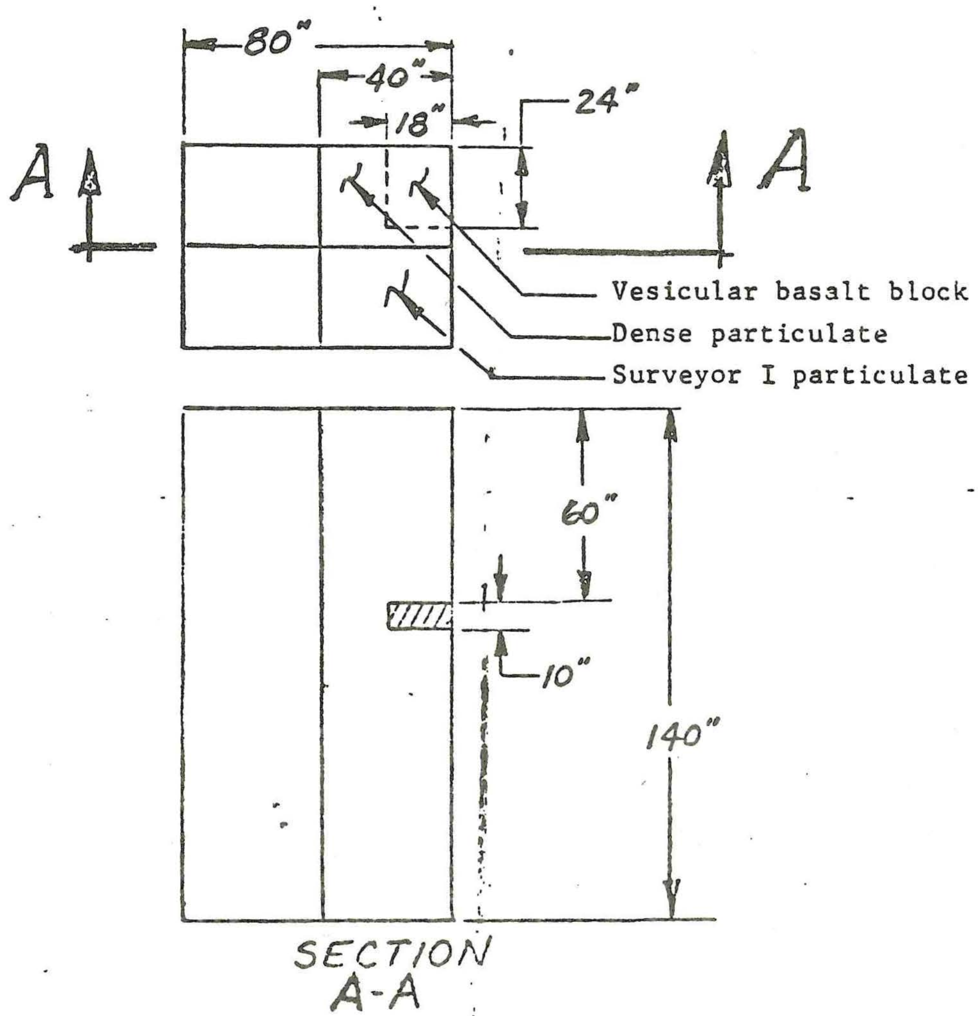


Figure 2 Lunar Soil Model

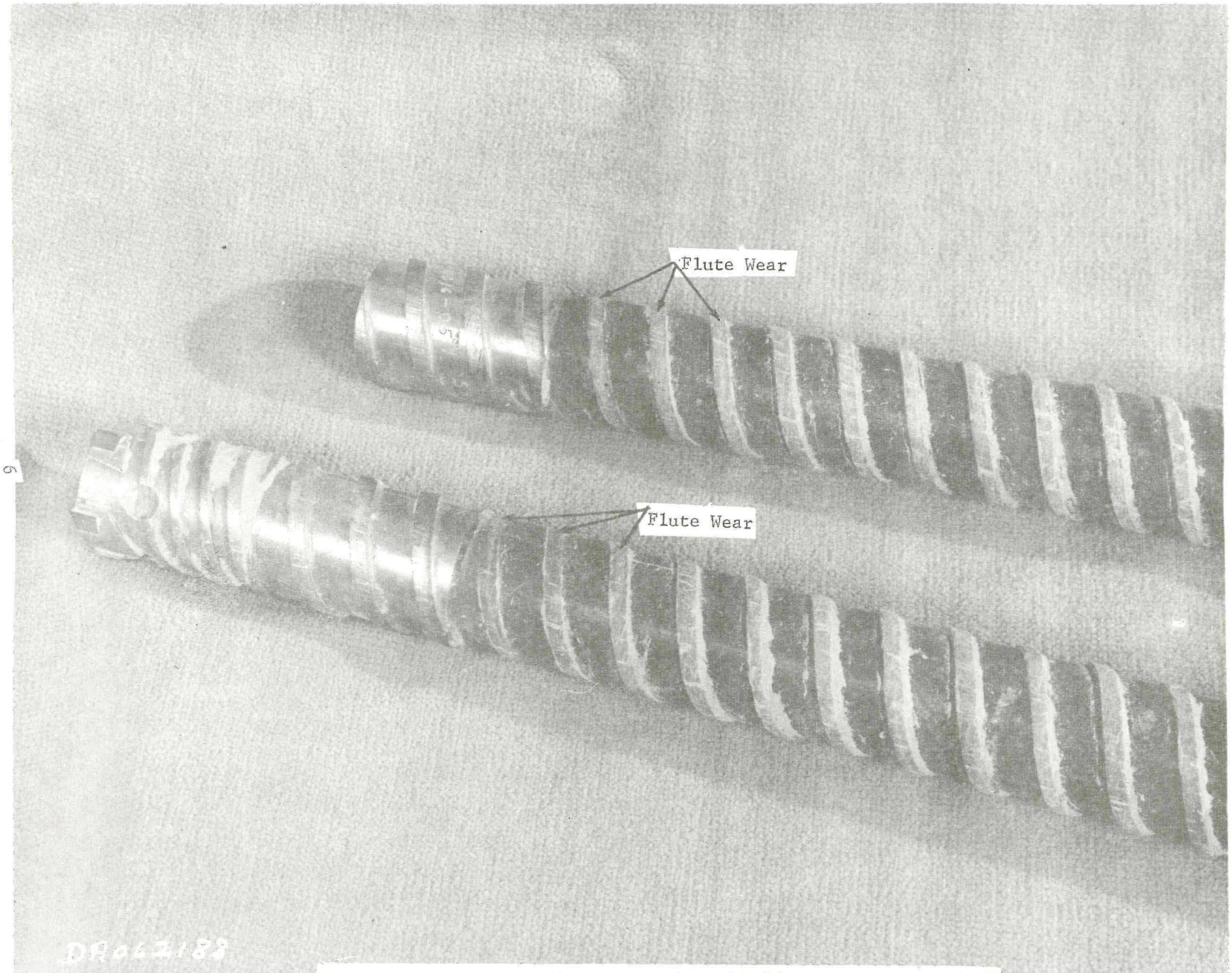


Figure 3 - Bore Stem Flute Wear after 40 (+) Minutes of Drilling

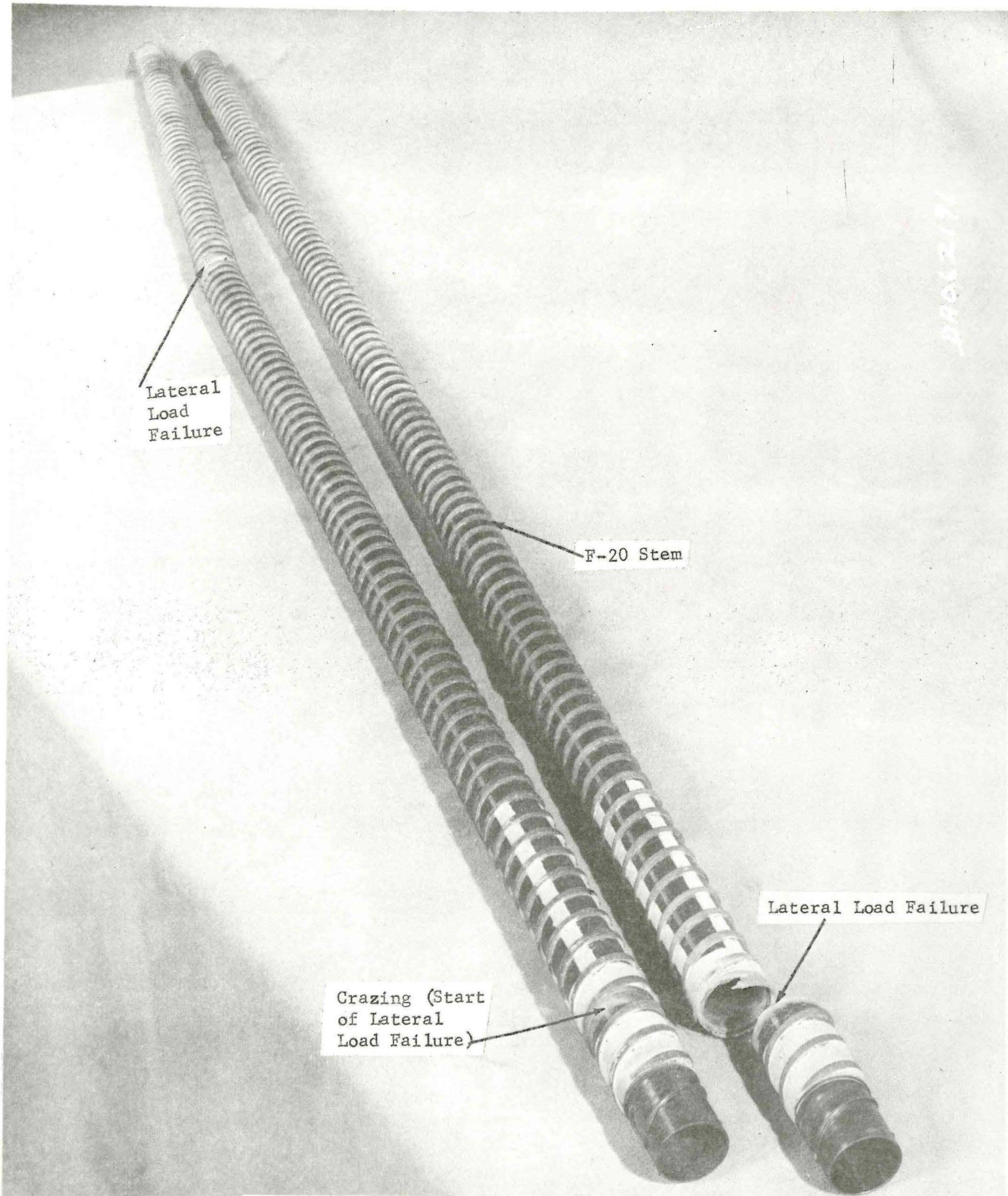


Figure 4 - Bore Stems after Lateral Load Tests

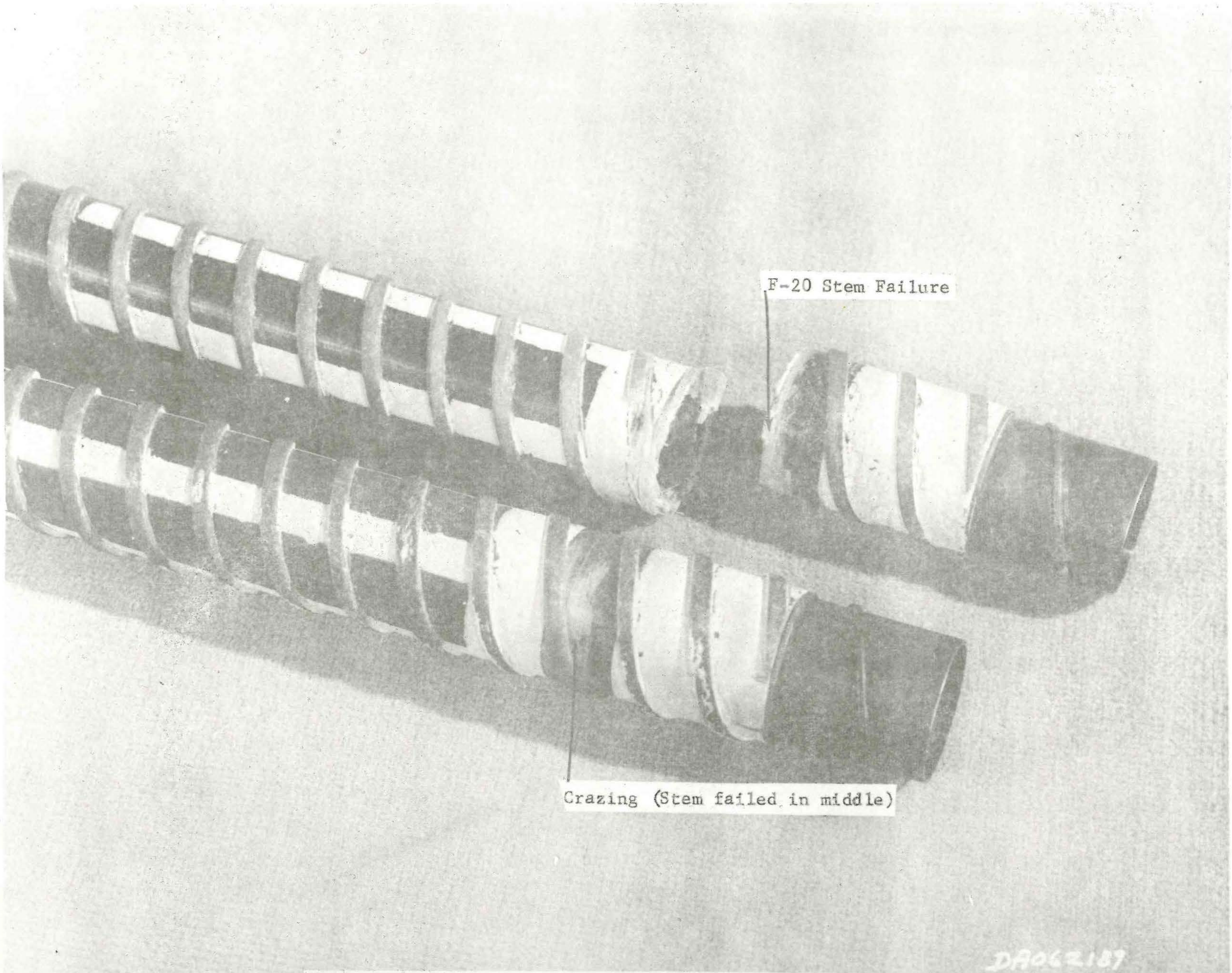


Figure 5 - Bore Stem Joints after Lateral Load Tests